ANNUAL CONFERENCE ON FIRE RESEARCH
Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

NIST

United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

ANNUAL CONFERENCE ON FIRE RESEARCH
Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

Carbon Monoxide Measurement Using a Near-Infrared Tunable Diode Laser

Linda G. Blevins and William M. Pitts
Building and Fire Research Laboratory
National Institute of Standards and Technology

David S. Bomse, Southwest Sciences, Inc.

One important goal of fire research is to study the formation and consumption of chemical species in and around a fire. Instruments which possess rapid temporal response are required for resolving species concentration fluctuations and for studying rapid events such fire suppression. Presently-used probe sampling methods are slow, and system temporal response is difficult to determine because it is a complex function of sampling line length, sample flow rate, and gas analyzer response time. The limitations of probe sampling provide motivation to explore new techniques for rapidly measuring species concentrations in and around fires.

One technique that shows promise is tunable diode laser absorption spectroscopy (TDLAS), in part because market forces in the communications industry have recently made room-temperature, near-infrared semiconductor lasers, detectors, and fiber optics readily available. Tunable diode lasers are spectrally narrow and can be rapidly tuned over molecular absorption transitions. These low-cost, compact, easy-to-use lasers feature single-mode performance, long-term wavelength stability, fiber-optic compatibility, low power consumption, and suitability for implementation of rapid, sensitive detection schemes. Diode lasers have been used to measure CO, O_2, CO_2, H_2O, and CH_4 concentrations, along with temperature, in and around flames [see, e.g., 1-3].

The overall goal of the present work is to study the feasibility of combining diode lasers with rapidly advancing fiber optic technology to develop an absorption probe for use in or around fires. A prototype diode laser system is being designed to detect carbon monoxide at temperatures between 300 K and 1200 K in fire gases partially obscured by soot.

Initial efforts are underway at NIST to evaluate TDLAS technology for measurement of CO concentration in fire gases. Wavelength modulation spectroscopy (WMS) is presently being explored. A diode laser system has been assembled which consists of an Indium Gallium Arsenide Phosphide (InGaAsP) distributed feedback near-infrared laser with temperature and current controllers, fiber-optic collimators for delivering and retrieving laser light, an InGaAs photodiode detector, and a digital lock-in amplifier. A search is underway for a CO line which is relatively free from interference by species such as H_2O. This is a challenging task since H_2O strongly absorbs throughout the near-infrared spectral region, especially at high temperatures.

The amount of light absorbed by a molecule at its linecenter wavenumber v_o (cm^{-1}) is quantified using the Lambert-Beer law, $I_v/I_{vo} = \exp[-S(T)g(v-v_0)NL]$, where I_v/I_{vo} is the fractional laser light transmittance at v_o, $S(T)$ is the temperature-dependent line strength (cm^{-1}/molecule·cm^{-2}), $g(v-v_o)$ is the line shape function (normalized to unit area) evaluated at v_o (cm), N is the number density of the absorber (molecule/cm^3), and L is the absorption path length (cm). Experimental determination of a species concentration involves measuring the fractional transmittance and the temperature. The number density of the absorber can then be computed from the known line strength, line shape function, and path length, and can be converted to concentration using the ideal gas law.
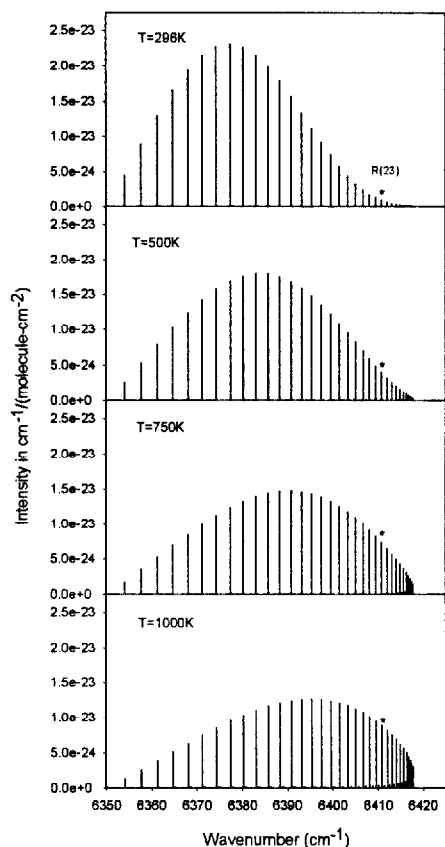
Fig. 1 Temperature-dependent line strengths for the R-branch of the second overtone of CO.

The temperature-dependent line strength for CO is obtained from the HITEMP database, which is a special version of HITRAN [4, 5]. Figure 1 depicts $S(T)$ for the R-branch of the 3ν overtone band at temperatures of 296 K, 500 K, 750 K, and 1000 K. The rotational line marked with a star on the graph corresponds to the R(23) line, and the figure indicates that $S(T)$ for this line increases from 8.3×10^{-25} cm^{-1}/molecule·cm^{-2} at 296 K to 8.8×10^{-24} cm^{-1}/molecule·cm^{-2} at 1000 K. Detection sensitivity depends on the product of $S(T)$ and $g(\nu-\nu_0)$. A Voigt profile, which accounts for both collisional and thermal (Doppler) line broadening, is appropriate for computing $g(\nu-\nu_0)$ for most fire-gas applications [2].

Figure 2 shows preliminary data collected in flame gases for the R(23) CO line. Data were taken on the lateral centerline of a Wolfhard-Parker CH$_4$/air diffusion flame at a height of 9 mm from the burner. At this location, [CO] = 8700 ppm, [H$_2$O] = 3.6 %, and T = 550 K along a 4.1-cm path [6,7]. The laser current was modulated at 20 kHz and detected at 80 kHz, so the signal is proportional to the fourth derivative of the lineshape (4f spectroscopy). Each scan is the difference between the demodulated detector signal and the 4f sloping background signal. Both are normalized by the d.c. component of the detector signal. The laser beam is delivered through a single-mode fiber-optic collimator and mirror-focused onto a detector. The spectrum is the average of 1000 sweeps, each of 26-ms duration. Increasing data point number on the abscissa represents decreasing wavenumber, and the resolved peak at point number 130 corresponds to the R(23) CO line at 6410.8 cm^{-1}. The figure demonstrates the potential for retrieving CO signals from hot fire gases with WMS.
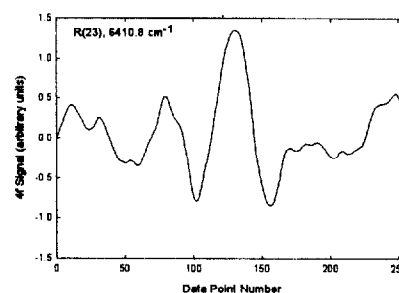

Fig. 2. 4f signal along lateral centerline at 9-mm height in WHP flame.

1. Silver, J.A., Kane, D. J., and Greenberg, P. S., *Applied Optics* 34:2787 (1995).

2. Allen, M.G., *Measurement Science and Technology* 9:545 (1998).

3. Mihalcea, R. M., Baer, D. S., and Hanson, R. K., *Measurement Science and Technology* 9:327 (1998).

4. Rothman, L.S., Gamache, R.R., Tipping, R.H., Rinsland, C.P., Smith, M.A.H., Benner, D. Chris, Devi, V. Malathy, Flaur, J.-M., Camy-Peyret, C., Perrin, A., Goldman, A., Massie, S.T., Brown, L.R., Toth, R.A., *Journal of Quantitative Spectroscopy and Radiative Transfer* 48:469 (1992).

5. Rothman, L.S., HITRAN home page, http://www.hitran.com/ (1998).

6. Miller, J.H., Elreedy, S., Ahvazi, B., Woldu, F., and Hassanzadeh, P., *Applied Optics* 32:6082 (1993).

7. Norton, T.S., Smyth, K.C., Miller, J.H., and Smooke, M.D., *Combustion Science and Technology* 90:1 (1993).